2009

Towards Enhancing Science as Inquiry: A Case Study from Inorganic Chemistry

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Abstract

There has been a strong belief within the science education community since the 1950's that science education ought to involve students in inquiry processes endemic to scientific practice as opposed to just learning the facts of science. This belief is reflected in the emphasis given to 'science as inquiry' in the National Science Education Standards Document (NRC, 1996) and the American Association for the Advancement of Science Benchmarks for Science Literacy (AAAS, 1993). In spite of this commitment to inquiry in our standards documents, it has been reported that students who have completed both a high school qualification and an undergraduate degree may not have experienced such inquiry-based science (Roth, 1998). That is, pre-service teachers are unlikely to have experienced either inquiry methods of teaching and learning or the discipline of science as inquiry in their own science education. In this paper the discipline of science as inquiry is the focus and an account is given of how a traditional laboratory exercise for the preparation of tin (IV) oxide was converted to an inquiry-based laboratory exercise through the use of historical material from the 19th century and through a focus on the status of the guiding principles and assumptions behind the determination of chemical composition.

Introduction

Scientific inquiry is characterized in the National Science Education Standards document (National Research Council, 1996:23) as:

> A multifaceted activity that involves observations; posing questions; examining books and other sources of information to see what is already known; planning investigations; reviewing what is already known in light of experimental evidence; using tools to gather, analyze, and interpret data; proposing answers, explanations, and predictions; and communicating the results.

It is significant that scientific inquiry was recognized as a 'multifaceted activity' because, as Grandy and Duschl (2007) point out, it has almost exclusively been associated with the hypothetico-deductive method to the exclusion of other key elements in the inquiry process. They identify these other key elements as theory development, conceptual change, and model construction along with the following caution (Grandy & Duschl, 2007:143): This is not to imply that scientists no longer engage in experiments. Rather, the role of experiments is situated in theory and model building, testing and revising, and the character of experiments is situated in how we choose to conduct observations and measurements; ie., data collection. The danger is privileging one aspect of doing science to the exclusion of others.

The term 'inquiry' has taken on almost an 'iconic' status in science education documents (AAAS, 1993; NRC, 1996) to the extent that one might be tempted to think that inquiry processes belonged only to the science discipline and were somehow excluded from all other scholarly endeavours. Surely all other scholarly disciplines feature inquiry otherwise they would not be scholarly? Could not the above statement by the National Research Council defining scientific inquiry also apply, with the possible exception of the word 'experimental', to all scholarly disciplines? What is it, then, that sets scientific inquiry apart from historical inquiry, or economics inquiry, or philosophical inquiry? The distinguishing feature must be the subject matter and the special tools by which data is gathered and knowledge is created in the discipline that sets it apart from other forms of inquiry. This is why Joseph Schwab (1962:102) considers that one cannot understand science as inquiry apart from the content of science. Goodrum, Hackling and Rennie (2000:145-146) make this point when they say that, "Inquiry means that students combine these scientific processes with scientific knowledge as they reason and think critically about evidence...". Rutherford (1964:84) claims that, "To separate conceptually scientific content from scientific inquiry is to make it highly probable that the student will properly understand neither". It is well argued by Rutherford that scientific concepts such as the universal law of gravitation cannot be separated from the experimental and theoretical inquiries used to produce the law. Unfortunately the impression is often created that inquiry should always take precedence over content in reformed curricula. For example, in a well-intentioned article by Edwards (1997:20) it is stated that in promoting student inquiry, "the focus is on inquiry, not in transmitting science concepts to students". While the intention of the author is to promote student-centred learning over teacher-centred transmission, the fact that scientific concepts are attached to transmission and not inquiry creates this impression of a divorce between inquiry and content. Rutherford (1964:80) insists that, "the choice is neither facts and laws nor inquiry and process; it is both facts and laws and inquiry and process".

Although scientific inquiry is sometimes portrayed as a methodical procedure there is universal agreement that there is no one scientific method or inquiry process in science. Schwab (1962:100) emphasizes the importance of different methods of inquiry within a science discipline and strongly opposes a doctrine of inquiry. "If one ends up with enquiry as involving a uniform procedure it will end up conveying, not science as enquiry, but a doctrine about knowledge and enquiry which is more questionable and less useful than our present dogmatic teaching of science". Well-intentioned authors [(Edwards,1997:18) for example] still speak, however, about "the step of the scientific method to solve problems...." as if there was one universal procedure for problem-solving. Schwab (1962:102) warned us in his Inglis Lecture even before the great curriculum reforms of the mid to late 1960's that scientific inquiry is "not a universal logic, it is only a generic envelope for a plurality of concrete inquiries".

A significant number of inquiry research papers acknowledge the distinction that Schwab (1962) originally made between 'teaching as inquiry' and 'science as inquiry'. Tamir (1983) identifies the latter in terms of what is taught and learned and the former as to how teaching and learning are executed. Rutherford (1964) identified with the distinction by speaking of inquiry as content or inquiry as pedagogic technique. Chiappetta (1997) deals with the two ways of thinking about inquiry in terms of general inquiry and scientific inquiry. General inquiry refers to teaching science by inquiry and scientific inquiry refers to teaching science as inquiry. Boujaoude (2004) distinguishes between teaching science as inquiry and teaching science through inquiry and makes the observation that science curricula tend to encourage the latter, what he terms as the 'doing science' phase, and neglects the former, what he terms as the 'minds-on' or 'thinking' science component. Lederman (2004:402) acknowledges the important function of 'doing science' but calls for a greater stress on 'thinking science' because "a stress on understandings about inquiry is clearly more consistent with the goal of scientific literacy than the more perennial stress on doing inquiry". This statement is consistent with that made by Schwab (1962:71) forty-two years earlier: "Of the two components-science as enquiry and the activity of inquiring- it is the former which should be given first priority as the objective of science teaching in the secondary school". However, a number of recently published papers on inquiry (Crawford, 2007; Roehrig, Kruse & Kern, 2007; Zion, Cohen & Amir, 2007) focus on the activity of inquiry rather than on 'science as inquiry' and even, in one case, claim Schwab in support. Zion et al (2007: 423) claim that "Schwab (1962) led the way for these reforms by describing inquiry as a way of teaching classroom science", without acknowledging that Schwab preferred the emphasis to be placed on 'science as inquiry', that is, on the nature of science.

To understand what Schwab (1962) meant by 'science as inquiry' it is worth re-reading his Inglis Lecture even though it was delivered over forty years ago. It remains, in my opinion, one of the best accounts of science as inquiry. Scientific knowledge is not self-evident (Wolpert, 1992). It depends on what Schwab calls the guiding principles of inquiry, the guiding conceptions, or the special way the scientist chooses to look at the world of nature. According to Rutherford (1964:83), for example, it was the invention of the concept of 'light ray' that enabled the law of reflection in a plane mirror to be articulated. "A light-ray is fictitious: its virtue is that it provides a useful way to talk about....the regularity of image reflection. It is the invention of the light-ray as the physical analogue of the Euclidean straight line, and the related acceptance of the correspondence between plane geometry and optical phenomena (rather than the discovery of the rule of equal angles), that was the key step here". The important point to note is that this conception of light-ray then dictates the nature of what Schwab calls the other constitutive components of scientific knowledge; the experimental techniques; the data obtained; the interpretation of the data; and the conclusions. Schwab strongly emphasizes how important it is for students to understand how difficult it often is to obtain data, how to get reproducible results, and how data are usually interpreted through the conceptions used to produce them. At certain periods in the history of science the conceptions have had to be changed in order to explain anomalous data thus demonstrating the dynamic and fluid character of scientific knowledge. It is partly in this context that Rutherford (1964) and Tamir (1983) suggested that if teachers are to successfully communicate something of the nature of science or science as inquiry to their students they should have some exposure to history and philosophy of science in their professional development.

A number of research studies of teachers participating in the teaching of science through inquiry methods projects (Aschbacher & Roth, 2002; Brown & Melear, 2006; Century & Levy, 2003; Crawford, 1999, 2007; Pine et al., 2006; Roehrig et al., 2007; Windschitl, 2002; Zion et al., 2007) demonstrate how difficult it is to engage school students in inquiry methods. Many of the teachers in these studies commented that they themselves had never experienced either the teaching of science through inquiry or the teaching of science as inquiry in either their undergraduate science studies or science methods courses, in spite of the earlier recommendations of researchers like Tamir (1983). Grandy and Duschl (2007) have recently renewed the call for the inclusion of science as inquiry in college and university science courses. In this paper an attempt is made to illustrate how a traditional college or university inorganic chemistry laboratory exercise might be recast into a format that draws upon some of the important elements of science as inquiry discussed in this introduction. In particular the experimental format for the preparation of tin(IV) oxide will be recast in a way which draws upon relevant history and philosophy of science; focuses on the relevant guiding conceptual principles and assumptions; gives significant attention to the acquisition of data and its interpretation; and illustrates how the 'rhetoric of conclusions' (Schwab, 1962) characteristic of much science education portrays a significant falsehood in the way scientific knowledge develops. While the teaching and learning of science as inquiry will be emphasized in this paper, some opportunities for teaching science through inquiry will also become evident.

This paper describes the first stage of a research project examining how 'nature of science' or 'science as inquiry' elements might be incorporated into the laboratory experiences of college and university students. The first stage of the project has involved choosing historical material likely to challenge student thinking about chemistry concepts and their underlying principles and choosing an experimental design likely to lead to issues in the interpretation of data. The tin/nitric acid reaction is chosen because it is one of the few metal/nitric acid reactions leading to the production of a solid oxide rather than the metal nitrate. The second stage of the project will examine in detail how students produce and interact with the experimental data and the associated historical material and the results of this stage will be reported at a later date. In this paper we set the framework and rationale for the study.

A Rationale for Choosing Historical Material for this Study

Ian Winchester (1989, p(i)) has observed two distinct tendencies in science teaching in the Western tradition. "The first is to treat science as something with results but without a history.....And the second is to treat science as something which can be nearly completely captured by working examples from a textbook *(or by doing recipe-based laboratory exercises-my addition)*. Both of these activities, namely, dwelling on agreed upon scientific results and standard examples, are important and part of the initiation into the complex of activities involved in a scientific discipline. But they fail to convey to the student......anything of the excitement of scientific discovery, of the conceptual problems involved in forging a new realm of scientific inquiry or of advancing in an old one, of the myriad difficulties of interpretation, theory construction, and abandonment or the moral and aesthetic problems faced in the process". So if one is interested in providing students with an opportunity to experience 'science as inquiry' or 'the nature of science', some exposure to its history will highlight how important theory and experiment are, for example, in the formation of scientific knowledge.

For the current project I have chosen to include an excerpt from Jane Marcet's 'Conversations in Chemistry' (1832) which deals particularly with a 19th century view of what happens when a metal reacts with an acid. The excerpt uses the caloric theory of heat to explain the strong emission of thermal energy in the metal/acid reaction and the oxygen theory of an acid to explain that the reaction always leads first to the formation of the metal oxide and then finally to the salt if enough acid is left to dissolve the oxide. This excerpt should, therefore, be most pertinent to the reaction at hand and give students an opportunity to observe how different theories of the past had an important role in explanation. Students are also presented with John Davy's (1812) preparation of Tin(IV) Oxide so comparisons can be made with their own experimental results.

The Traditional Laboratory Exercise for the preparation of Tin(IV) Oxide used by students in the past

The nature of the traditional laboratory exercise is shown in Figure 1 and forms part of the p-block chemistry course studied by our undergraduate chemistry students in their second year as part of their BSc or BSc/BTch degree course. The students will have completed first-year degree level chemistry.

The Preparation of tin(IV) oxide

1. Weigh accurately, to four decimal places, a crucible and lid. Place about 0.5 gram of finely divided tin in the crucible and weigh accurately the crucible, lid, and contents and determine the mass of the tin to four decimal places.
2. Place the crucible, containing the tin, on a pipe-clay triangle set up in the fumehood. Add dropwise 70% nitric acid until no more brown fumes are emitted. Heat gently until the brown fumes are expelled. Safety Note: Wear safety glasses and gloves.
3. When all the tin has apparently reacted, place the lid on the crucible and heat strongly for five minutes.
4. Allow to cool to room temperature and then weigh the crucible, lid, and contents to four decimal places.
5. Repeat the strong heating for another five minutes, followed by cooling to room temperature and weighing. Repeat until a constant weight is achieved.
6. From your measurements confirm that the buff-coloured product is indeed SnO_2 by determining the mole ratio of tin to oxygen in the compound.

Figure 1.
Traditional instructions for the preparation of tin(IV) oxide.

This exercise is a confirmatory exercise with no inquiry-based features or nature of chemistry features. A set of five results obtained by the author is given in Table 1 for the exercise as written in Figure 1 and is representative of that typically obtained by students for this exercise. Students normally conclude that the product of the reaction is consistent with the formula SnO_2 given some allowance for experimental error. Two important questions that need to be addressed are as follows. Could this laboratory exercise be rewritten in a way that did not assume that one was preparing tin(IV) oxide but where students were required to think about the nature of the possible products of the reaction given their current chemical experience and that drawn from the history of science? Could the typical student data obtained for this exercise (Table 1) be used to challenge the conclusions typically drawn, highlight potential problems in the technique used, and/or challenge the guiding principles and assumptions used by the chemist in an exercise like this? The following is an attempt to answer these questions.

Table 1. Five results (R1-R5) obtained by the author for the exercise in Figure 1.

Quantity	R1	R2	R3	R4	R5
mass of tin/g	0.4891	0.5085	0.5023	0.5319	0.5198
mass of product/g	0.6061	0.6384	0.6265	0.6554	0.6479
mass of oxygen (non-metal)/g	0.1170	0.1299	0.1242	0.1235	0.1281
mol Sn: mol O	1: 1.77	1: 1.90	1: 1.83	1: 1.72	1: 1.83
mass% oxygen (non-metal)	19.3	20.3	19.8	18.8	19.8

Towards a 'science as inquiry' approach to the preparation of Tin(IV) Oxide

One could use an open inquiry approach to answer the question, What happens when concentrated nitric acid is added to tin and, if a reaction occurs, determine what the products of the reaction are? The problem with this approach here is that one is asking students to complete, over a period most likely no longer than a laboratory session of three hours or at most a semester, a task which took chemists hundreds of years to complete. I have therefore chosen to structure the inquiry in such a way that important background knowledge is made available to the student as a preliminary step in the whole process. This background knowledge highlights the guiding principles used by a chemist when studying matter and its chemical composition and deals with some practical laboratory matters pertinent to the investigation. As mentioned in the introduction, this is a critical part of the nature of science and the teaching and learning of science as inquiry. The guiding principles and assumptions need to be highlighted if they are to be later questioned or confirmed. Specifically, the background knowledge made available to students contains practical advice on how to perform a metal-acid reaction; the problems associated with using concentrated nitric acid on metals and the related reason as to why 70 percent nitric acid is used 2; thinking of composition in terms of mass percentage of metal and non-metal parts; thinking of composition in terms of atoms and the related mol percentage of atoms of the elements; the law of constant composition; and the existence of two oxidation states of tin (tin(II) and tin(IV)) with the possibility of compounds possessing both oxidation states. A 'science as inquiry' approach to the preparation of tin(IV) oxide, developed from a study of the science education and history of science literature and the author's experience with this reaction over a number of years, is now outlined as follows.

This 'science as inquiry' approach does not identify the solid product of the reaction but challenges the student to think through the process to the likely nature of the product after having read the background information and an historical account of the reaction of metals in the presence of acids. The investigation is therefore inquiry-based but is structured to the extent that quantities of materials are stipulated in the procedure which is reproduced in Figure 2. This is the scenario currently used with my science students and relies on the background information specified previously.

An investigation of the product of the reaction between tin and concentrated nitric acid

1. Weigh accurately, to four decimal places, a crucible and lid. Place about 0.5 gram of finely divided tin in the crucible and weigh accurately the crucible, lid, and contents and determine the mass of the tin to four decimal places.

2. Place the crucible, containing the tin, on a pipe-clay triangle set up in the fumehood. Add dropwise 70% nitric acid until no more brown fumes are emitted. Heat gently until the brown fumes are expelled.
Safety Note: Wear safety glasses and gloves.

3. When all the tin has apparently reacted, place the lid on the crucible and heat strongly for five minutes.

4. Allow to cool to room temperature and then weigh the crucible, lid, and contents to four decimal places.

5. Repeat the strong heating for another five minutes, followed by cooling to room temperature and weighing. Repeat until a constant weight is achieved.

6. From your measurements you need to ascertain the formula of the solid product of this reaction by determining the simplest whole number mole ratio of the elements in the product and/or by determining the mass percentage of metal and non-metal and comparing with values determined for possible formulae.

As a start, to help you with this determination, you need to think about what happens in a metal-acid reaction. Study the following account of a metal-acid reaction given by Jane Marcet in 1832 and answer the accompanying questions.When you have done this determine the nature and formula of your product from your results.

Figure 2. Instructions for the preparation of tin(IV) oxide from an inquiry-based perspective.

Jane Marcet was a frequent attendee of the public chemistry lectures given by Humphry Davy and Michael Faraday at the Royal Institution in London and developed a love and skill for writing chemistry dialogues. Her account (Marcet, 1832) of what happens when an acid is added to a metal is most entertaining and is reproduced in Figure 3. She reflects Lavoisier's view of acids as oxygen carriers and also the caloric model of heat which regarded heat as a material substance without weight. The conversation is between Emily, Caroline, and Mrs B. As students read this account, they are asked to consider the following questions.

1. According to Marcet all acids contain which element in common?

2. What substance corresponds to the thick yellow vapour observed when nitric acid was added to copper? Did you also get this coloured vapour on mixing tin with nitric acid?

3. How does Marcet use the material theory of heat (heat is caloric) to explain the evolution of heat in the metal-acid reaction? Before you answer this question you may want to read the summary of the caloric theory of heat provided. The summary given to students refers to caloric as a massless fluid possessed by all elements and compounds with gases possessing more caloric than liquids which possess more caloric than solids. Converting solids to liquids to gases involves gaining caloric and .converting gases to liquids to solids involves releasing caloric. The more caloric possessed by a substance per unit volume the higher its temperature will be.

Emily:
Metals have, then, three ways of obtaining oxygen; from the atmosphere, from water, and from acids.
Mrs B:
The two first you have already witnessed, and I shall now show you how metals take the oxygen from an acid. This bottle contains nitric acid; I shall pour some of it over this piece of copper leaf.....
Caroline:
Oh, what a disagreeable smell!
Emily:
And what is it that produces the effervescence and that thick yellow vapour?
Mrs B:
It is the acid, which, being abandoned by the greatest part of its oxygen, is converted into a weaker acid, which escapes in the form of a gas.
Caroline:
And whence proceeds this heat?
Mrs B:
Indeed, Caroline, I think you might now be able to answer that question yourself.
Caroline:
Perhaps it is that the oxygen enters into the metal in a more solid state than it existed in the acid, in consequence of which caloric is disengaged. The effervescence is now over; therefore I suppose that the metal is already oxidated.
Mrs B:
Yes. There is another important connection between metals and acids, with which I must make you acquainted. Metals, when in the state of oxides, are capable of being dissolved by acids. In this operation they enter into a chemical combination with the acid, and form an entirely new compound.
Caroline:
But what difference is there between the oxidation and the dissolution of the metal by the acid?
Mrs B
In the first case, the metal merely combines with a portion of oxygen taken from the acid, which is thus partly deoxygenated, as in the instance you have just seen; in the second case, the metal, after being previously oxidated, is actually dissolved in the acid, and enters into a chemical combination with it, without producing any further decomposition or effervescence. This complete combination of an oxide and an acid forms a peculiar and important class of compound salts.
Emily:
The difference between an oxide and a compound salt, therefore, is very obvious; the one consists of a metal and oxygen; the other of an oxide and an acid.
Mrs B:
Very well: and you will be careful to remember that the metals are incapable of entering into this combination with acids, unless they are previously oxidated; therefore, whenever you bring a metal in contact with an acid, it will be first oxidated and afterwards dissolved, provided that there be a sufficient quantity of acid for both operations.

Figure 3. Jane Marcet's dialogue on the metal-acid reaction

4. What is Marcet's understanding of the structure of a salt?

5. Marcet identifies two stages in the reaction between a metal and an acid. What are the two stages? Were these two stages observed in the reaction between tin and nitric acid? Explain.

Having read the Marcet dialogue and answered the questions students are then requested to use this knowledge and their experimental results to determine the formula of the solid product.

From the background information given to students, prior experience of chemical reactions, and Marcet's dialogue, students, on reflection, are expected to suggest the possibility of nitrate or oxide as the product of the tin-nitric acid reaction. If students have difficulty arriving at this conclusion, and some students do have difficulty, they are asked to read the Marcet dialogue again and to review their answers to the questions associated with the dialogue. The way students respond to this challenge will be studied in more detail in the second phase of this research project. Only preliminary details of student responses are available at this stage but the responses are detailed enough to suggest that not all students will find this challenge easy. Given that tin can form tin(II) and tin(IV) compounds, one might expect the possibility of nitrate or oxide each in two possible oxidation states. Also, there is the possibility of mixed oxides, that is, oxides containing both oxidation states of tin in oxides like Sn_2O_3[Sn(II)O:Sn(IV)O_2] and Sn_3O_4[2Sn(II)O:Sn(IV)O_2]. At this point students are encouraged to write down the formulae for the possible products of the reaction. Having thought of up to about six possible formulae students are asked to determine if any of these formulae are consistent with the mass percentage of metal and non-metal determined experimentally. Six examples and their metal and non-metal mass percentages are shown in Table 2. Unlike copper, iron, zinc, and lead, it is clear from the typical results for mass percentage of non-metal in Table 1 that tin does not produce the nitrate salt but forms a composition closest to the dioxide (SnO_2).

While this analysis should lead students to the result that SnO_2 is the most likely product of the reaction, one has to ask whether considerable doubt could accompany this conclusion given the range of student data typically obtained and shown in Table 1. What might cause the molar ratio of tin to oxygen to be not quite equal to 1:2 or the mass percentage of oxygen to be not quite equal to 21.3 percent? Could the experimental average molar ratio of 1:1.81 be explained by the presence of unreacted tin, or the presence of a small amount of SnO in addition to SnO_2? These ideas can be checked by asking students to assume that 10 percent of the product by mass was either unreacted Sn or incompletely oxidized SnO, for example, and see if this reduces the molar ratio of tin to oxygen from 1:2 to 1:x where x is less than 2. These are ideas that students will not necessarily think of but they can be challenged to check the possibilities through calculation. As it turns out the calculation yields a tin to oxygen molar ratio of 1:1.77 for unreacted tin in the product and a ratio of 1:1.86 for the presence of SnO in the product. Both possibilities therefore lead to a tin to oxygen molar ratio in the direction of the experimental results.There is often more than one possibility that might fit a scenario and students need to confront this aspect of the nature of science and think about how one might decide between the possibilities. The possibilities listed here are actually in the form of hypotheses that are accessible to students and can be tested. Other possibilities exist, of course, but it is essential that not too many alternatives are presented as this can confuse students. One other possibility will almost certainly present itself to students and that is the question of the accuracy of the experimental technique. This is usually the first possibility that students consider when questioned about the experimental results. In what sense could the experimental technique be improved and do suggested changes lead to more congruent results? This exercise illustrates how difficult the acquisition and interpretation of data can be in chemistry.

Table 2. Formulae and mass percentage for six different proposed products of the tin-nitric acid reaction.

Compound (Molar mass)	Mass% Sn	Mass% O or NO_3
SnO (134 g mol^{-1})	88.1	11.9
SnO_2 (150 g mol^{-1})	78.7	21.3
Sn_2O_3 (285.4 g mol^{-1})	83.2	16.8
Sn_3O_4 (420.1 g mol^{-1})	84.8	15.2
$Sn(NO_3)_2$ (242 g mol^{-1})	48.8	51.2
$Sn(NO_3)_4$ (366 g mol^{-1})	32.2	67.8

Another important consideration here is whether the law of constant composition could be rightly challenged given the spread of compositions shown in Table 1. Could the atomic hypothesis used to produce the molar ratios in Table 1 and the mass percentage compositions in Table 2 also be challenged? Are the experimentally determined compositions close enough to those expected to warrant the retention of these well-known guiding principles? Many students initially have difficulty with such questions because they are accustomed to a science education where answers are either correct or incorrect. What about situations like that presented here where it might be difficult to judge whether there is a legitimate basis to challenge a law? This does give students an opportunity to express an opinion related to some experimentally determined data, and to learn that the interpretation of data is not always a straight forward matter. A number of chemists of the 19th century, including the great French chemist Berthollet, were not convinced of the law of constant composition, for example, and believed composition could change continuously within certain limits. Dalton, on the other hand, believed that composition was invariant unless there was a different atomic combination. That is, Dalton viewed changing composition as a discontinuous phenomenon based on atomic theory, while Berthollet viewed changing composition as a continuous phenomenon (Leicester, 1971:155). What is important here is that, based on the data in Table 1, students can be led to sympathise with the struggles early chemists had in coming to terms with the notion of compound composition and the notion of matter as atomic in nature. An important lesson in interpreting data is the observation that the scientific profession would be in utter chaos if long-standing laws were overthrown as soon as someone produced results which seemed to challenge the laws. It is not until a large number of studies point in the direction of an anomaly that laws are seriously challenged.

Early 19th century chemists did explore the reaction between tin and nitric acid with varying degrees of success (de Berg, 2008). John Davy, brother to Sir Humphry Davy, describes the reaction as follows (Davy,1812:194).

42.5 grains of tin, which had been precipitated from the muriat (chloride) of this metal by zinc, were heated with nitric acid in a platina crucible, and slowly converted into peroxide; the acid and water were driven off by gentle evaporation at first, and afterwards by a strong red heat continued for a quarter of an hour. The peroxide thus produced was of a light yellow colour, and being very gradually dried, it was semi-transparent, and hard enough to scratch glass; it weighed 54.25 grains. Hence, as 42.5 grains of tin acquire, on conversion into peroxide, 11.75 grains of oxygene, this oxide appears to contain 21.66 per cent of oxygene,...

His mass percentage of oxygen (21.66%) is a little closer to the theoretical SnO_2 value (21.3%) than the results in Table 1 (18.8-20.3%) but it is difficult to compare the results adequately given the level of accuracy of weight measurements in 1812. Nevertheless the description is very interesting from three points of view; firstly, that of the mass units used (grains) in the early 19th century in England. The grain measure of mass has its origins in agricultural antiquity when a single seed of a typical wheat or barley cereal was used as a unit (grain) for mass. Given the variability of such a mass, the grain was eventually standardized to represent precisely 64.79891 milligrams. This is equivalent to 15.43 grains per gram. So students can now calculate the gram mass of tin that John Davy used in his experiment. Some medications in the USA still quote their active ingredients in grain units. For example, aspirin is labelled as 325 mg (5 gr) per tablet.

A second interesting feature of Davy's description is his preparation of tin for the reaction with nitric acid. Why did he not use already available samples of tin, a metal which had been known from antiquity? And what is the chemical equation for his preparation of tin? Finally, the colour of the SnO_2 prepared corresponds to that found in the five experiments leading to the data in Table 1. But the colour quoted in the SI Chemical Data book (Aylward & Findlay, 2008:86) is white. Now it is true that when the nitric acid is first added to the tin a white solid product forms but this changes to a light yellow or buff colour when strongly heated. It is interesting that Davy also observed this.

Conclusion

Grandy and Duschl (2007:158) summarize current research findings in science teaching as follows. " Research shows that prevailing models of science teaching are lesson based rather than unit based, emphasize concept learning rather than knowledge system learning, and focus inquiry lessons on completing experiments rather than on testing and revising explanatory models". One can see just from the illustrations given in this paper that inquiry processes take time and will mean choosing to reduce content coverage to accomodate inquiry processes. This may be another reason why teachers are reluctant to engage in deep inquiry processes in the classroom. As Grandy and Duschl (2007:158) continue to say, "The unfolding of data and evidence takes time and is another reason why effective inquiry units are longer in length. By pausing instruction to allow students to discuss and debate what they know, what they believe and what evidence they have to support their ideas, their thinking is made visible thus enabling the monitoring and assessment of the communication of information and of the thinking". This orientation to teaching and learning does produce a dilemma for the tertiary chemistry educator. There is a perceived need to give students access to the breadth of knowledge and skills in the discipline so that they emerge from their formal education with a comprehensive understanding of chemistry concepts and, in addition, be equipped for a range of roles in the chemistry profession. On the other hand new demands are being placed on chemistry educators to reduce breadth in order to increase the depth of knowledge and intellectual skills along the lines described by Grandy and Duschl. One cannot really argue against such demands for intellectual skills which address the epistemological issues of big-picture chemistry, particularly if we are in the business of education as opposed to training, but like many other recommendations in education the challenge is to try to achieve some balance between both approaches.

This paper has attempted to show how some of the concerns voiced by Schwab over 40 years ago, and more recently described by Grandy and Duschl (2007), might be addressed in an inorganic chemistry laboratory and class session. The scenario introduced here potentially gives an opportunity for students to sympathise with some of the challenges chemists faced in the 19th century in coming to terms with the atomic view of matter and the nature of chemical composition. There is much labour and research required in the advancement of chemical knowledge and students should experience some of this dynamic character of knowledge production if they are not to view chemical knowledge as a 'rhetoric of conclusions'. The second phase of this project will entail an in-depth study of the way students engage in this kind of experience. What specific difficulties do students relate when they are challenged to think about the security, origin, and nature of their knowledge and the discipline's knowledge base? How do students engage with historical material? Is their picture of chemistry more enlightened by such an approach? It is hoped that the analysis offered in this paper will encourage chemistry educators to persevere with attempting to introduce students to chemistry as inquiry because, if philosophers like Schwab are correct, the benefits should outweigh potential difficulties for both teacher, student, and the discipline of chemistry. The second phase of the project should shed some light on this prospect.

Notes

Moles of tin can be calculated from the mass of tin used. If one assumes that the increase in mass of the crucible contents is due only to the addition of oxygen, then moles of oxygen atoms can be calculated from the mass increase.

The use of very concentrated nitric acid with metals tends to place an impervious oxide layer on the surface of the metal thus preventing reaction of all the metal present. Seventy percent nitric acid is strong enough to react all the metal vigorously but not so strong to cause the reaction to cease.

Marcet's mechanism described here reflects Lavoisier's understanding of acid action on a metal. Other alternatives are possible of course. For example, the nitrate of tin could be formed initially and when heated strongly could form the oxide. Lead nitrate, for example, forms PbO when heated.

Kane (1851:370-371) also reports a pale yellow colour for the peroxide of tin. "It is most readily prepared by pouring the liquid nitric acid, sp.gr. 1.42 on metallic tin, in foil or powder; the action is very violent, and the metal is totally converted into a white powder, which is the hydrated peroxide. By ignition the water is given off; and the anhydrous oxide remains of a pale yellow colour".

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includes ion pairs. This form is known as Onsager's "triangle reaction" network (8). The relationships between equilibrium constants then are: $K_{sp}=[Na^+][Cl^-]=K_3$ $K_1 \cdot K_2 \cdot K_3=1$

K_1 and K_2 involve $(Na^+Cl^-)(aq)$ contact ion pairs which are not the most abundant species present; hence K_1 and K_2 values would be <1 which in turn will make the K_{sp} value >1. However, the important point to note is that the product of $[Na^+][Cl^-]$ is still constant and our original definition of solubility product remains valid. However, since the $[Na^+]$ and $[Cl^-]$ concentrations are smaller than in V1 due to the presence of ion pairs the solubility product should be smaller than V1 prediction.

The best value for K_{sp} is then obtained from V2 because the activity coefficients account for non-ideality of solutions caused by various secondary processes.

There are several messages and pedagogically important issues arising from this work. First, how can the concept of chemical equilibrium learnt in Year I and applied to ideal solutions be applied outside this narrow textbook context (i.e. sparsely soluble salts). Second, the work highlights the effects of extreme conditions (e.g. high ion concentrations of saturated solutions) on the behavior of species involved in the equilibrium, i.e. the difference between ideal and non-ideal solutions. Third, it demonstrates to students how a seemingly simple question whose answer can be obtained by plugging numbers into the known equation subsumes a wealth of important chemical concepts. The subject of this article also involves lateral thinking by encouraging students to link and relate concepts like equilibrium, activity coefficient, molar concentration, ion hydration and ion-pair formation. This lateral thinking is brought about by the expansion of understanding of a known concept as new material is being learnt.

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